Simulation of Inverse Piezoelectric effect in degradation AlGaN/GaN devices

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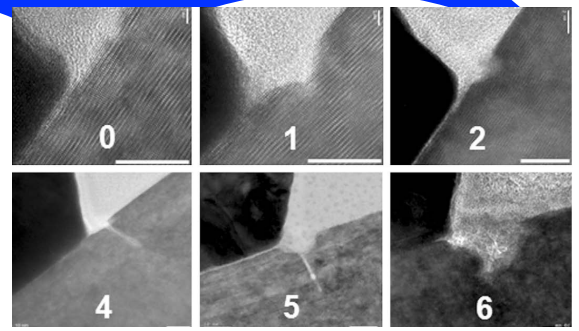
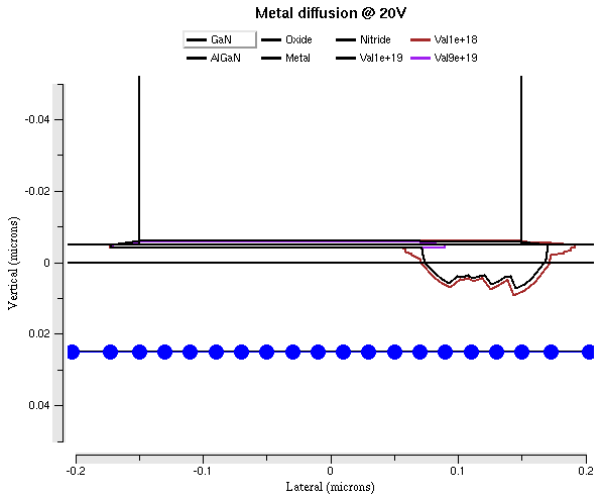
Simulation Approach

FLOORS





t=0, As Built

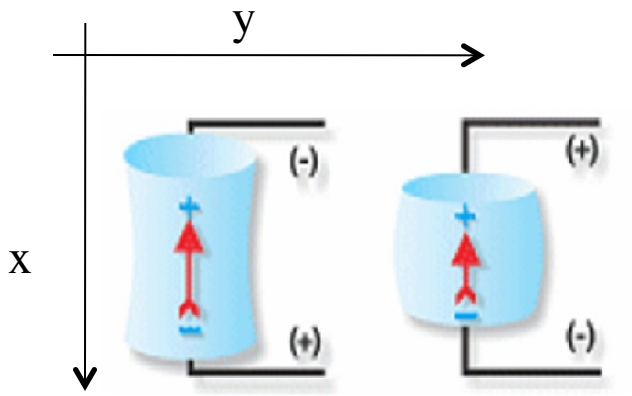
1] Park S.Y, Kim, M.J et al Microelectronics Reliability 49 2009 pp:478– 483

t>0, Degradation

Strain from Inverse Piezoelectric effect

1) Relationship (reduced to linear) between electric field, E and mechanical strain, ε: $\boldsymbol{\varepsilon_i = d_{ij} E_j}$ where j=1…3 and i=1….6

2) Assuming GaN crystal oriented such that polarization is vertical , $\varepsilon_{xx} = d_{33}E_x$, $\varepsilon_{yy} = d_{31}E_y$



Assuming constant d_{33}, d_{13}, d_{15} resultant strains given by:

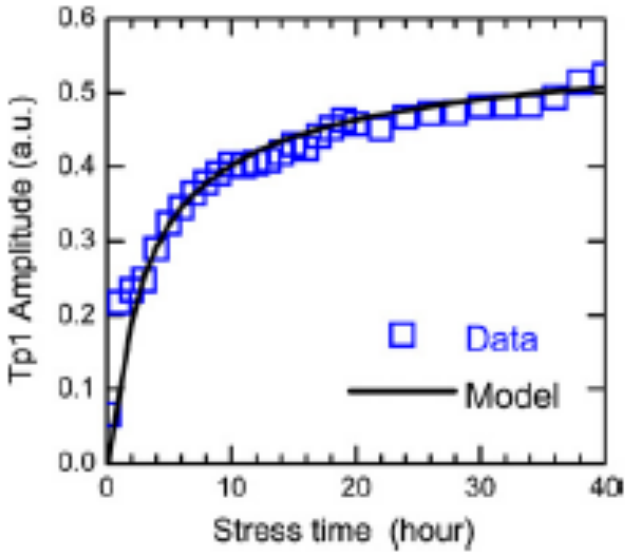
$$\begin{pmatrix} \epsilon_{xx} \\ \epsilon_{yy} \\ \epsilon_{xy} \end{pmatrix} = \begin{pmatrix} d_{33} & 0 \\ d_{31} & 0 \\ 0 & d_{15} \end{pmatrix} \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

GaN: d_{33} =3.4pm/V , d_{31} =-1.7pm/V , d_{15} =3.1pm/V

Relating Impurity Diffusion to Strain

- Trap concentration increases over time and matched to an infinite source diffusion model:

$$Tp1(z,t) = Tp1_{surface\ \rho}\left[1 - erf\left(\frac{z}{2\sqrt{Dt}}\right)\right]$$



- Strain known to enhance diffusion:

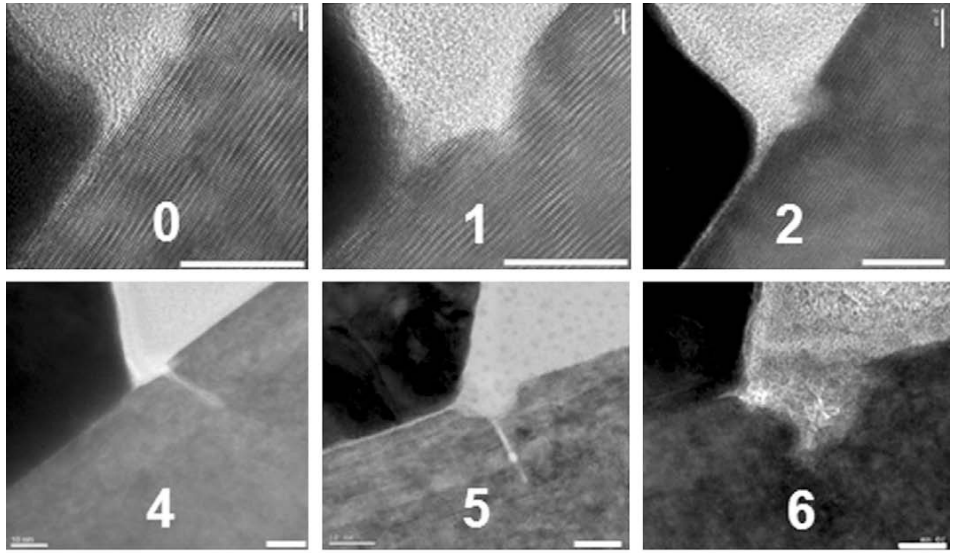
$$D' = D * exp\left(\frac{Q's}{kT}\right)$$

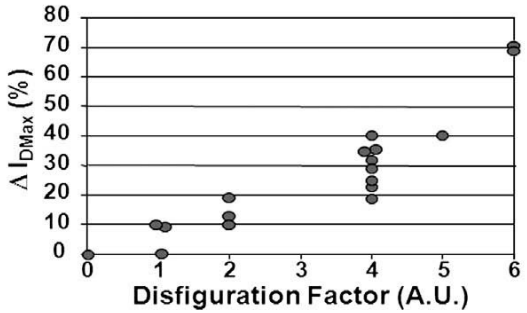
  - D' = Enhanced diffusivity due to strain
  - D = Diffusivity of Ni in AlGaN at given temp, T
  - Q' = Energy per unit strain
  - s = Total strain at point

2] Kuball, M et al Microelectronics Reliability 51 2011 pp:195– 200

TEM images of degraded devices

- Physical degradation related to I_D reduction
- $I_{D\,MAX}$ reduction as much as 70%
- Non-recoverable

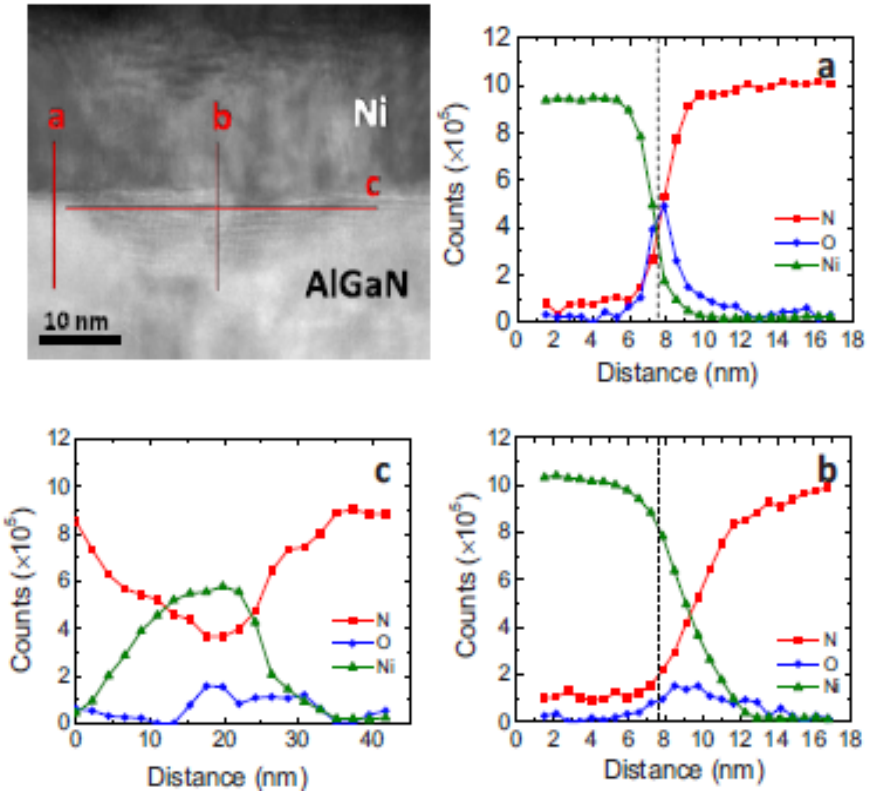




1] Park S.Y, Kim, M.J et al Microelectronics Reliability 49 2009 pp:478– 483

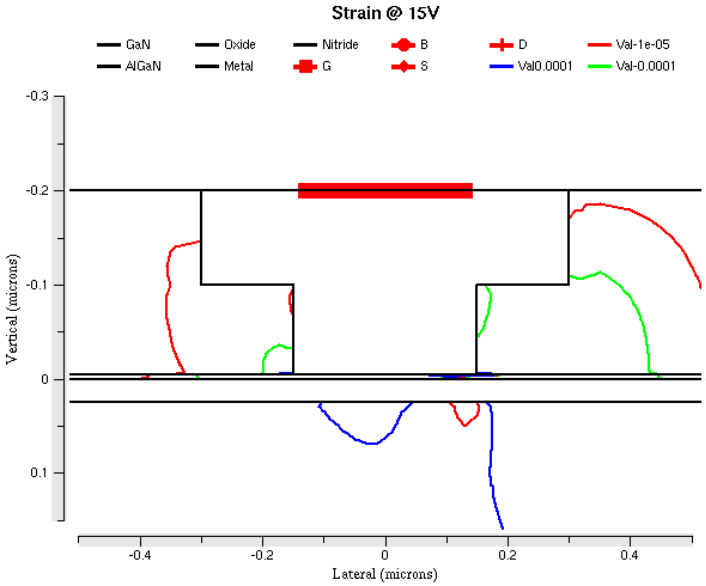
TEM images metal diffusion

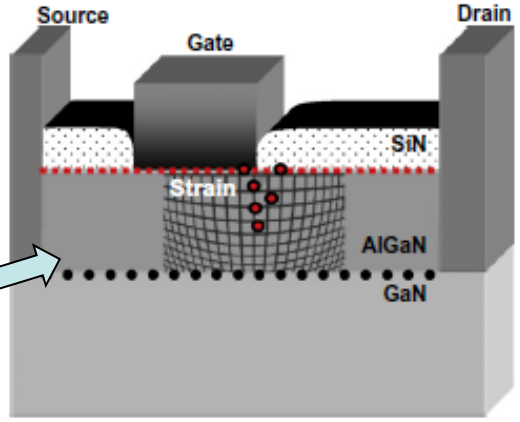
- Observed for Ni/Au gates commonly near edges
- Off-state, step-stressed
- EELS line scans show Ni diffusion into AlGaN

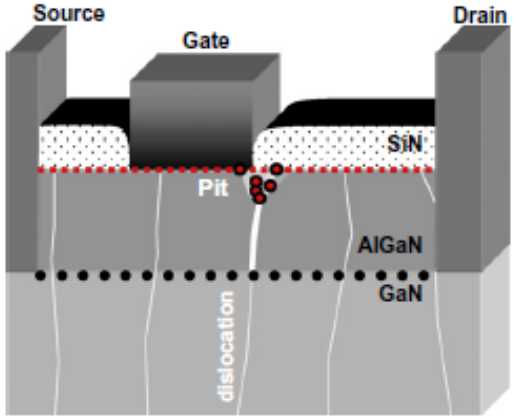


3] Ren, F et al. JVST B 5 Microelectronics and Nanometer structures Apr 2011

Strain distribution around T-gate







- Impurity diffusion driven by strain
- Pit formation suggests diffusion

3] Kuball, M et al Microelectronics Reliability 51 2011 pp:195– 200

Simulation Flowchart

Strain distribution within structure determined as a function of bias → $\begin{pmatrix}\epsilon_{xx}\\ \epsilon_{yy}\\ \epsilon_{xy}\end{pmatrix} = \begin{pmatrix}d_{33} & 0\\ d_{31} & 0\\ 0 & d_{15}\end{pmatrix}\begin{pmatrix}E_x\\ E_y\end{pmatrix}$

⇩

Diffusion of metal impurity driven by strain → $D' = D * exp\left(\frac{Q's}{kT}\right)$

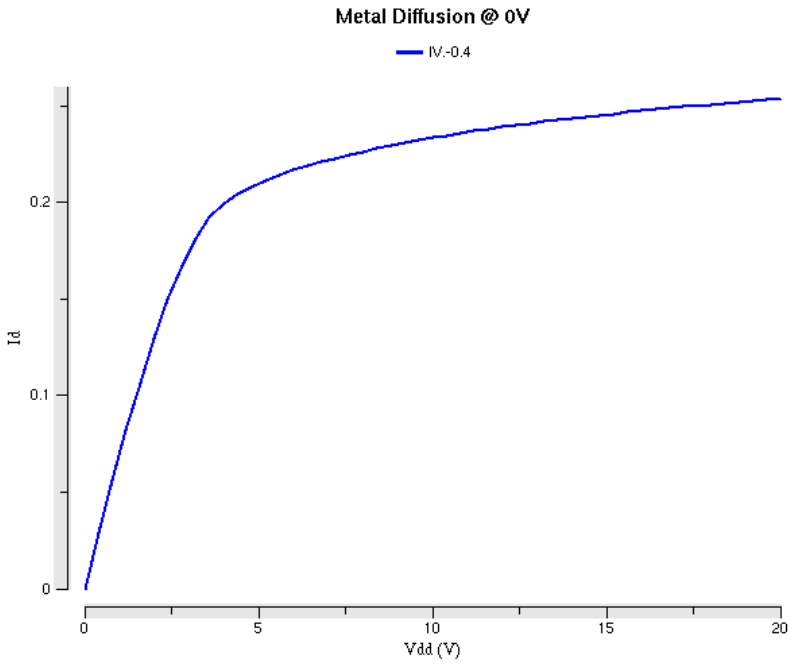
⇩

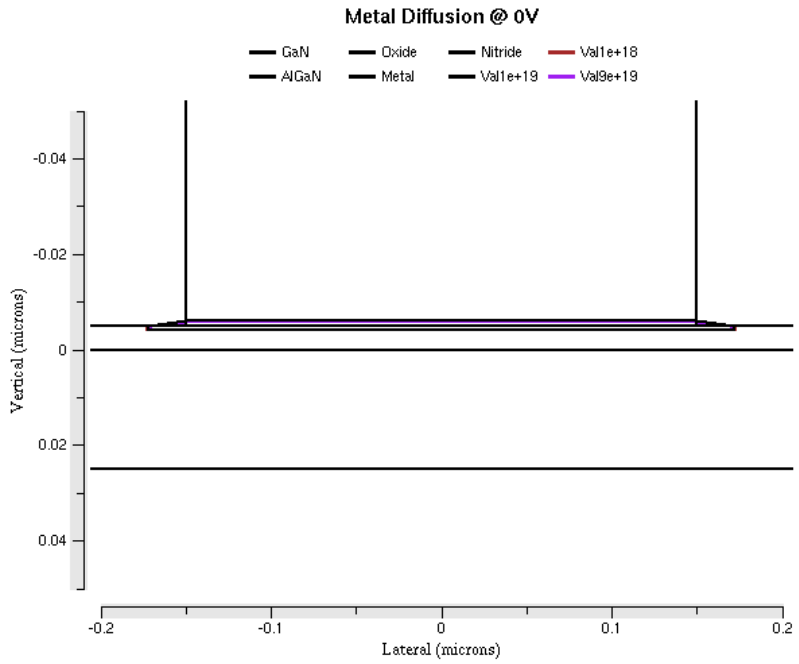
Metal impurity profile fed into Poisson's equation → $\frac{d^2\varphi(x)}{dx^2} = -\frac{\rho(x) + Impurity(x)}{\epsilon}$

⇩

IV curves determined for each impurity profile → $\frac{d(Elec)}{dt} = n * \mu_n * \frac{d^2\emptyset(x)}{dx^2}$

IV decrease & Metal diffusion





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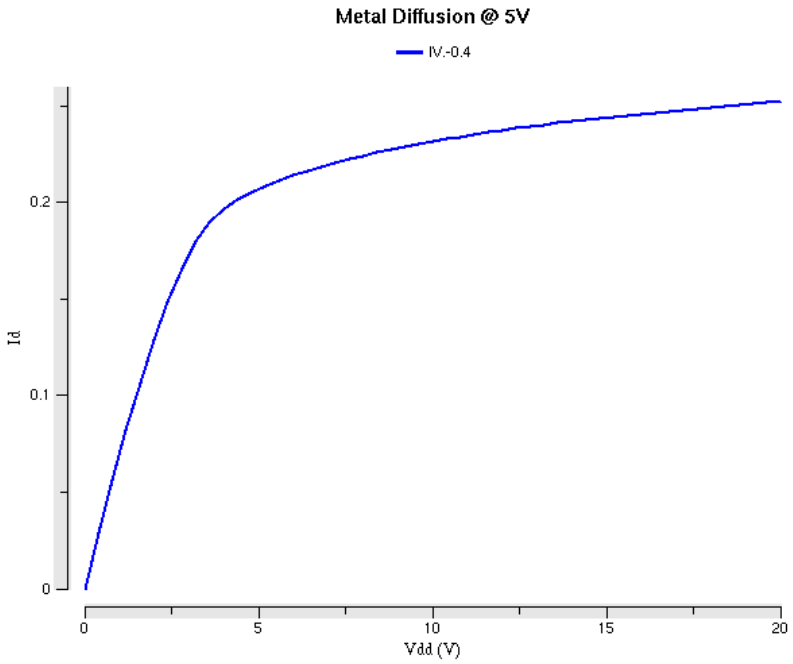

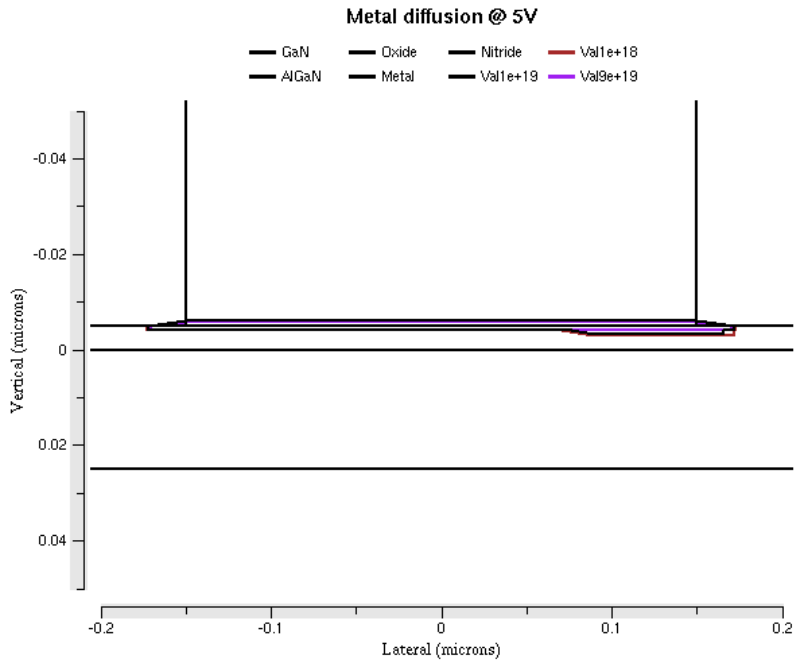

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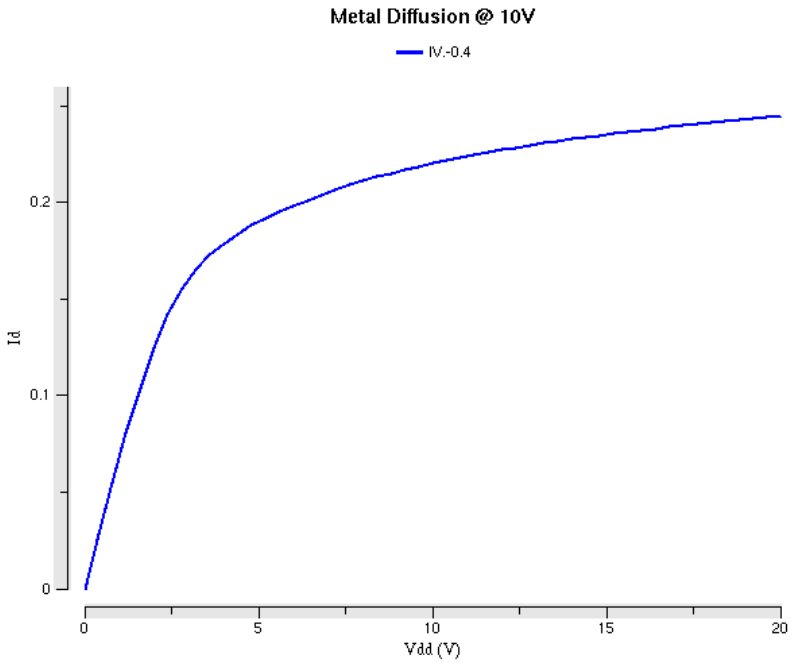

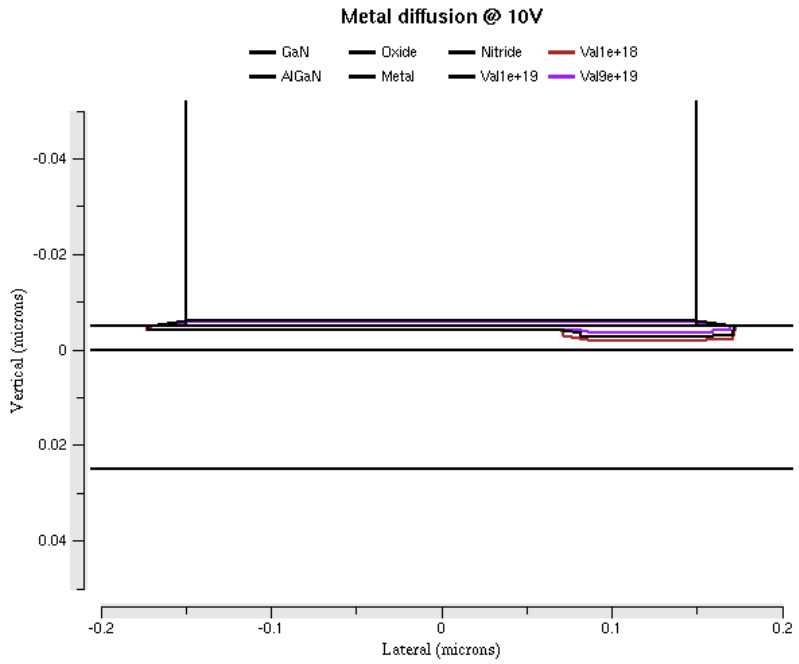

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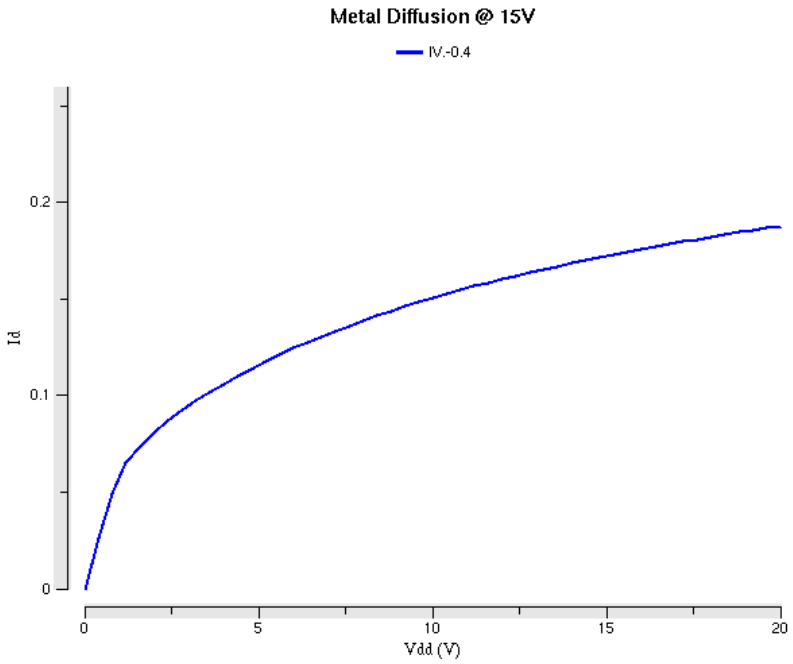
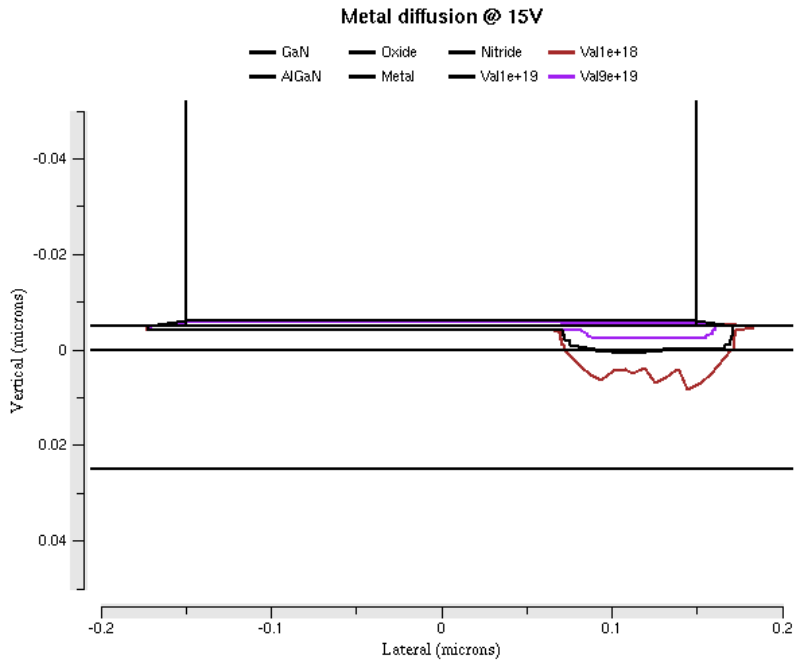
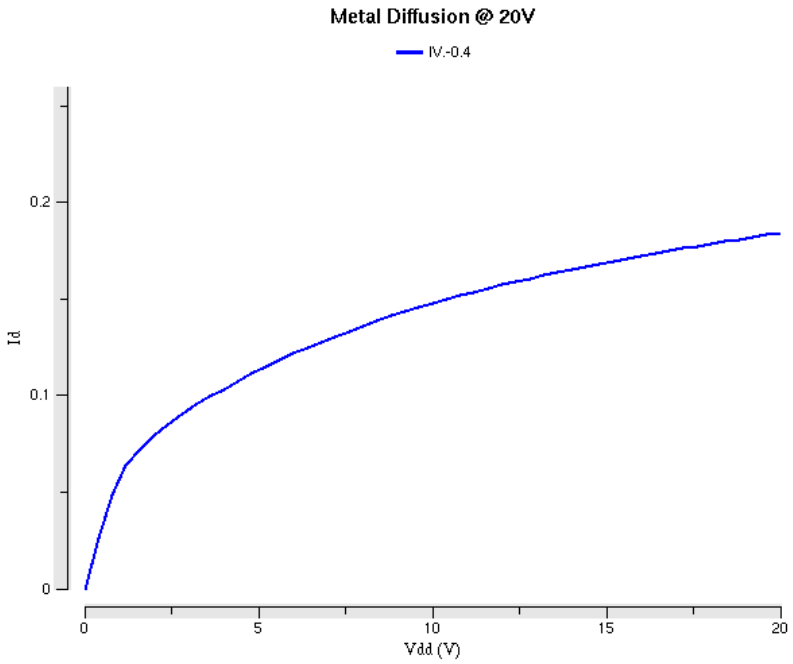
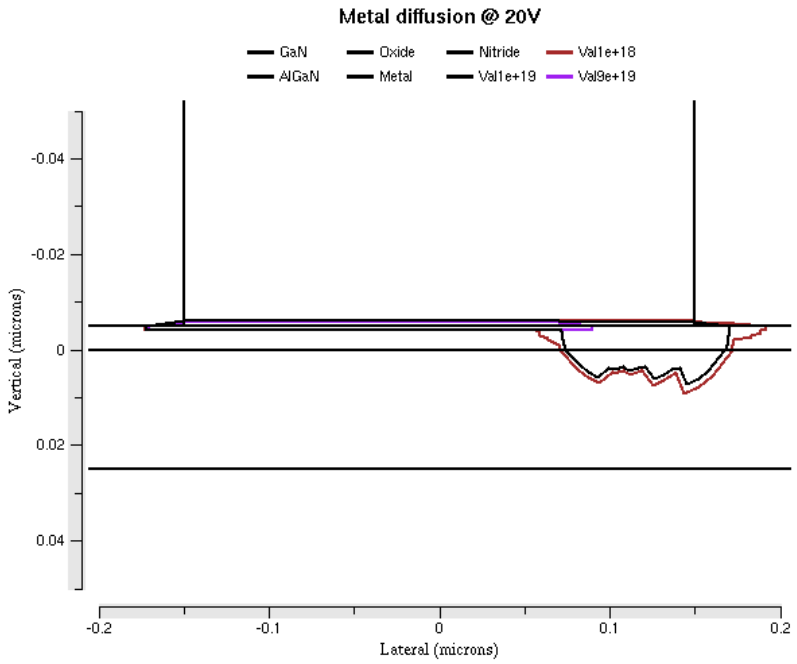


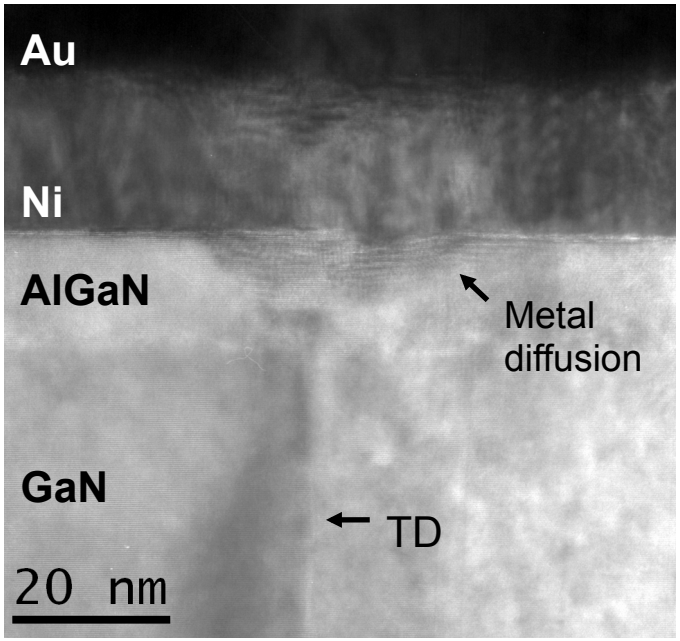


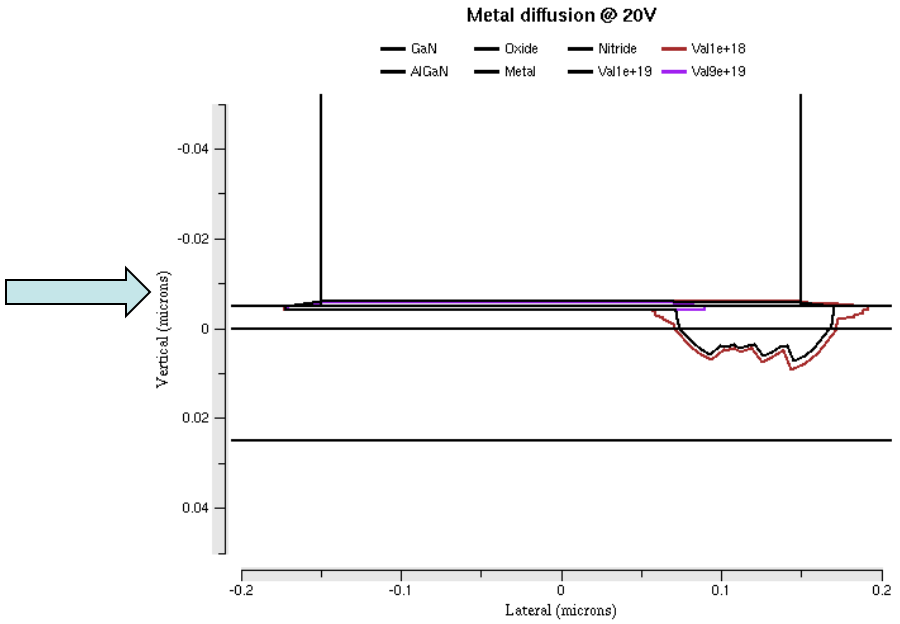
IV decrease & Metal diffusion





Physical data vs Simulation





- Simulated $I_{D\,MAX}$ drop ~ 40% for similar physical degradation.

- Critical Vd in simulation still does not match physical data. (15V vs ~38V)

4] Joh, J, del Alamo J. Electron Device Letters, IEEE JNL Volume 29, No 4. 2008 pp:287– 289

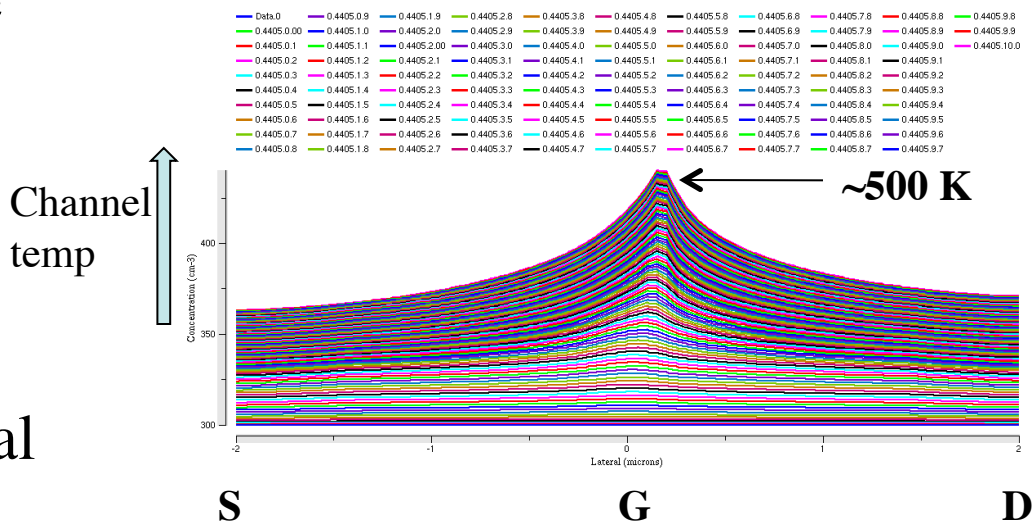
Future work: Effect of Temperature

For High Power state, device has appreciable self heating

~500K @ Vd=10V

*Future model will include contributions from thermal increase at gate edge.

* T↑ ,E↓ ,Diffusivity↑



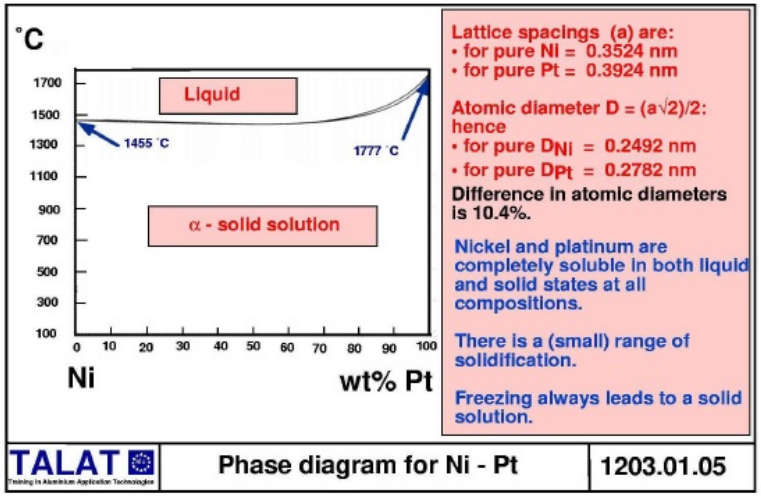
References

- 1] Park S.Y, Kim, M.J et al Microelectronics Reliability 49 2009 pp:478– 483
- 2] Kuball, M et al Microelectronics Reliability 51 2011 pp:195– 200
- 3] Ren, F et al. JVST B 5 Microelectronics and Nanometer structures Apr 2011
- 4] Joh, J, del Alamo J. Electron Device Letters, IEEE JNL Volume 29, No 4. 2008 pp: 287– 289

Back up Slides

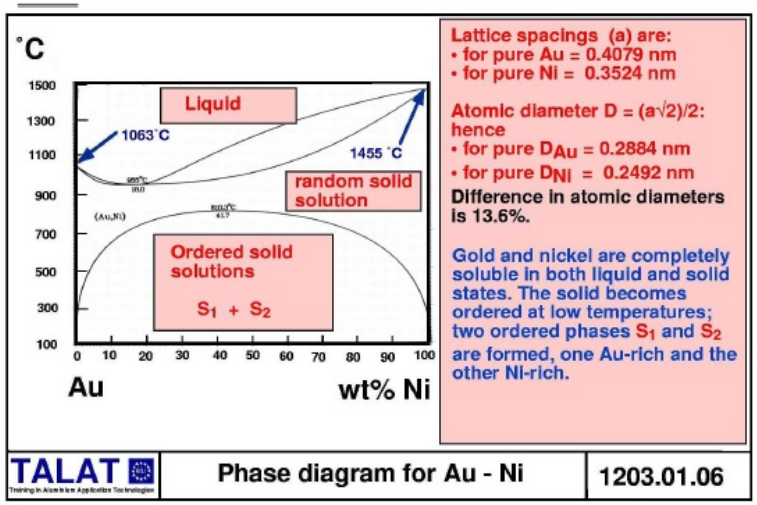
Ni/Pt Phase diagram

• Full range of Ni/Pt alloy forms 1 phase below 1450°C

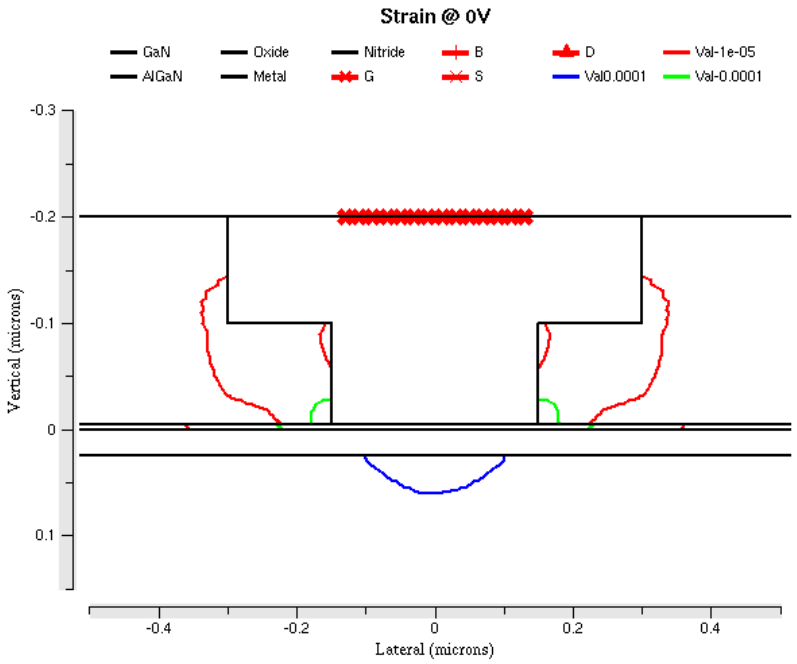


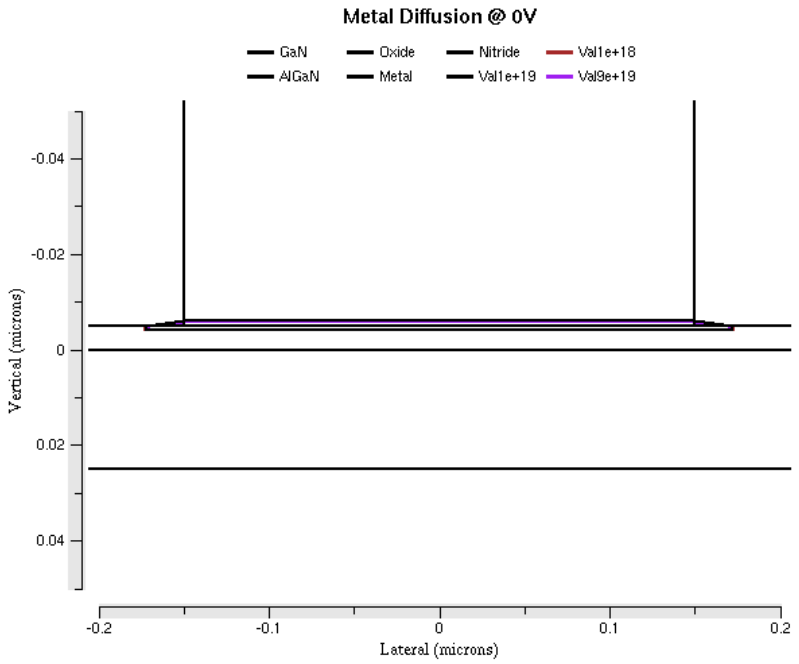
Ni/Au Phase diagram

• large range of Ni/Au alloy forms 2 phases below 700°C



Strain evolution & Metal diffusion





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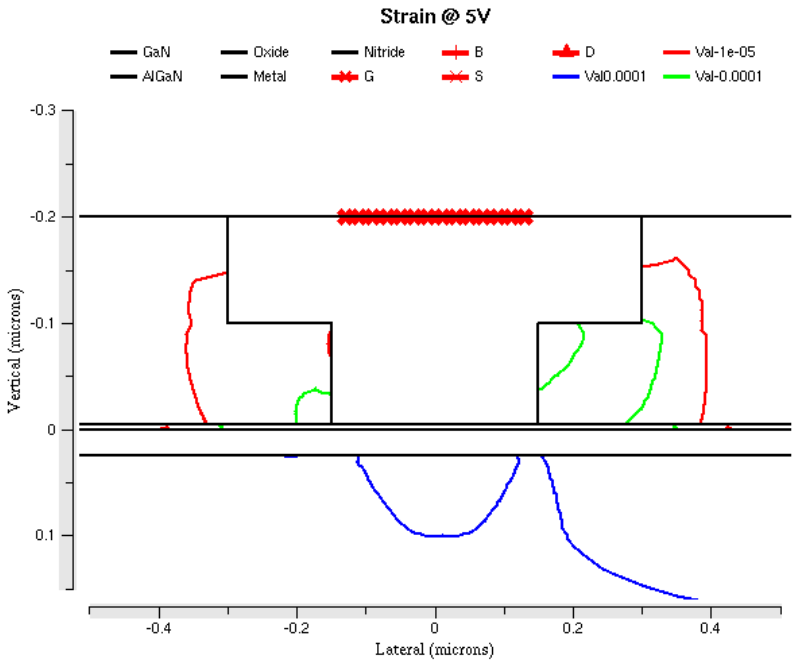

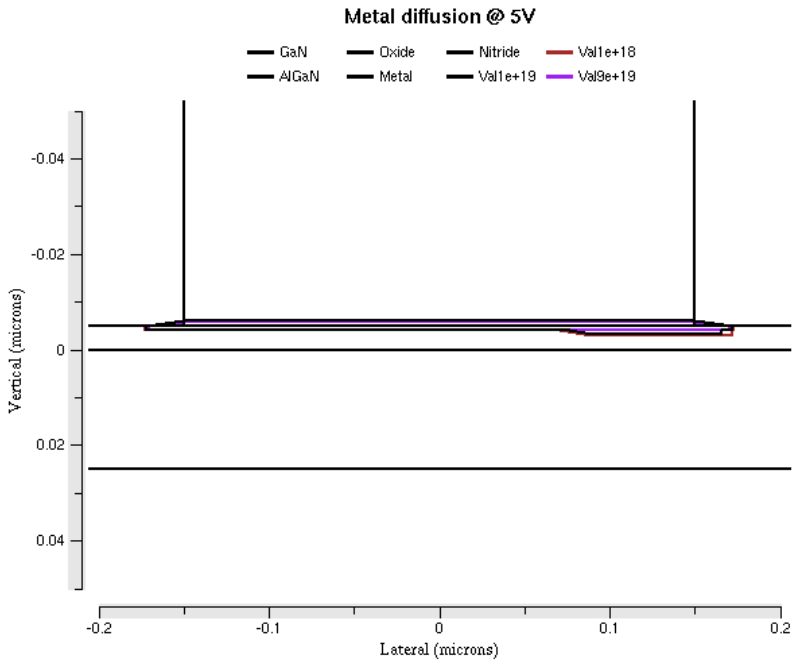

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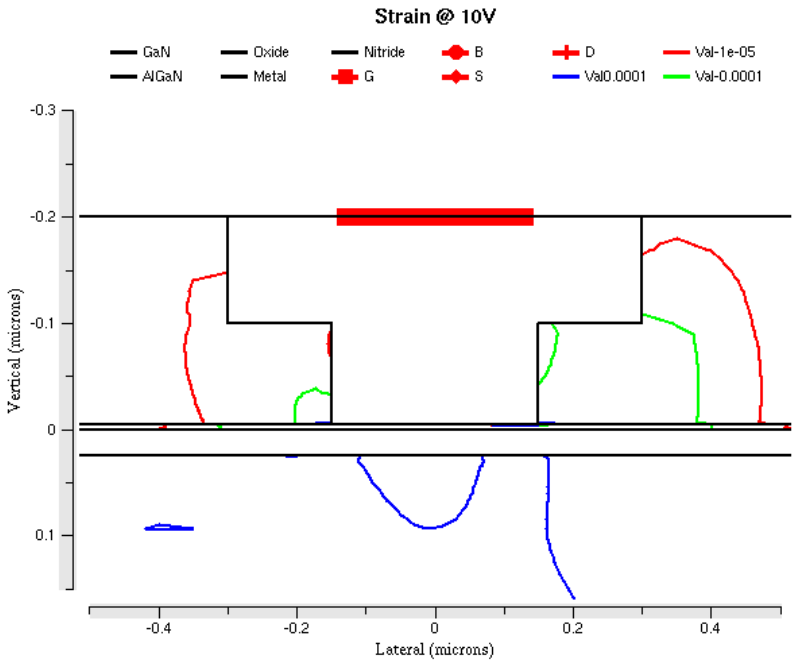

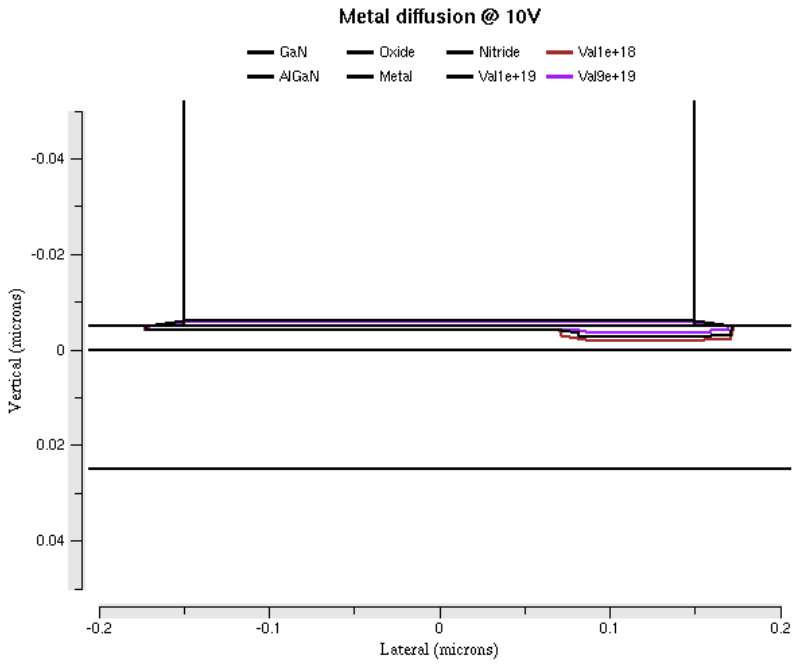

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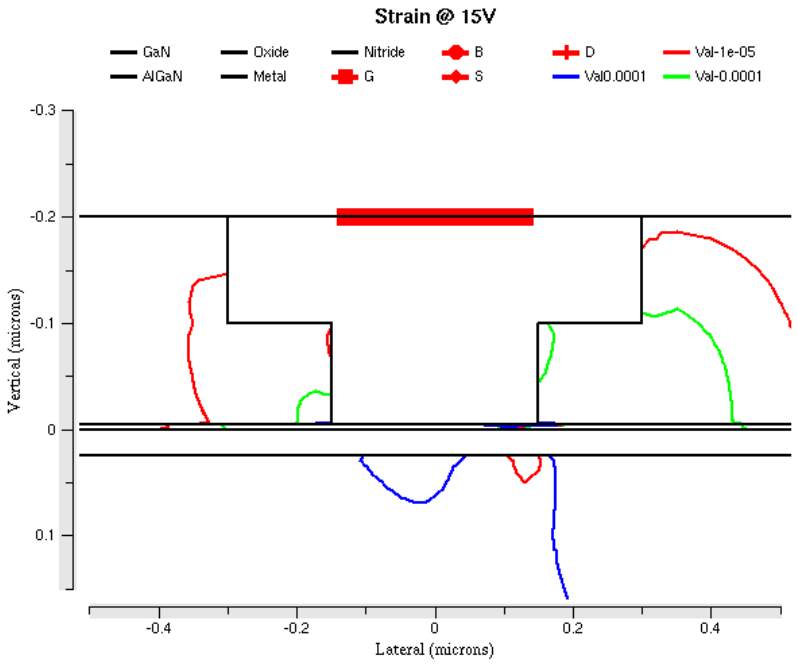

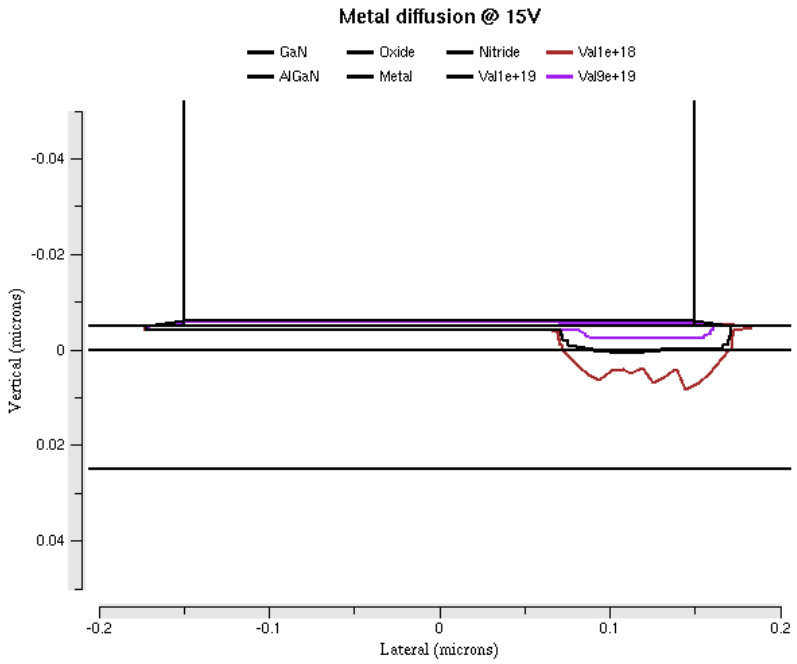

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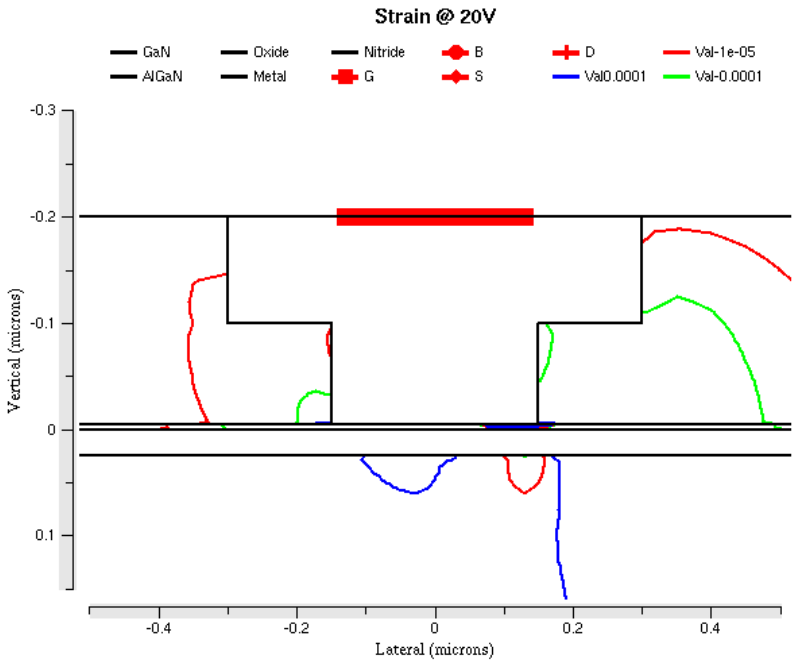

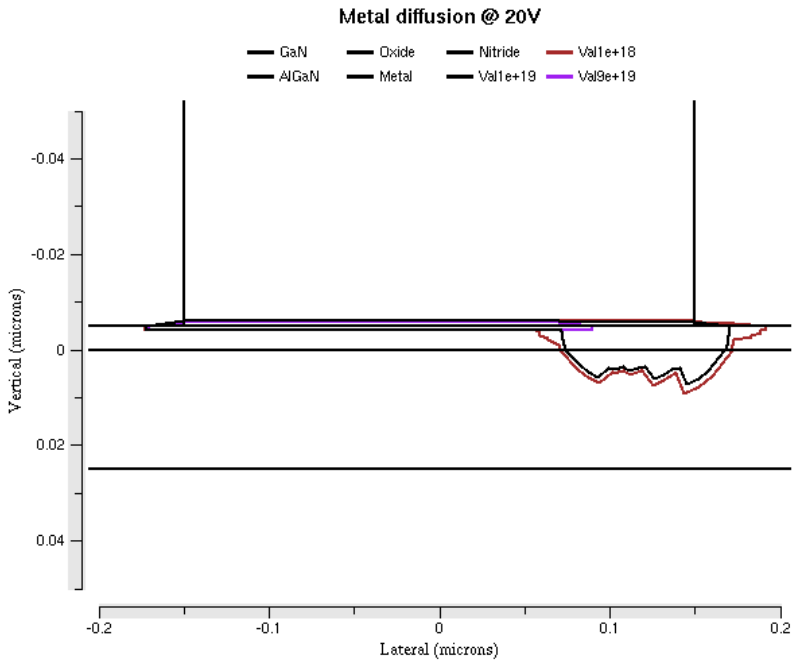

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